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Risø National Laboratory, DK-4000 Roskilde, Denmark
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PHYSICS DEPARTMENT ANNUAL PROGRESS REPORT

1 January - 31 December 1982

Abstract. Research in the Physics Department at Risø National Laboratory covers three main fields: Condensed Matter Physics, Plasma Physics and Meteorology. The report is a progress report describing the principal activities in these fields for the period from 1 January to 31 December 1982.
The condensed matters physics research is predominantly experimental utilising diffraction of neutrons, x-rays, and synchrotron x-ray radiation. The research topics range from studies of structure, excitations and phase transitions in model systems to studies of ion transport, texture and recrystallization kinetics with a more applied nature.
The plasma physics reserch is partly experimental and partly theoretical. A study of pellet-plasma interaction is of applied nature and aimed at assessing the possibilities of refuelling a fusion reactor by shooting deuterium-tritium pellets into the plasma. A study of the fundamental physics of plasmas deals with investigations of wave propacation properties, instabilities, solitons turbulence, etc.
The research and applied work within meteorology lies within micrometereology and the subjects range from surface energy balance studies, over studies of the general structure of atmospheric coherence and boundary layer response to change in surface elevation, to specific studies of turbulent dispersion and deposition of airborne material. As part of the applied work within meteorology and wind energy, the test station for small windmills tests and licences windmills for the Danish market and offers consulting assistance for the Danish windmill manufacturers.

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PREFACE

Research ir the Physics Department covers three main fields:

Condensed matter physics
Plasma physics
Metereology

The principal activities in these fields are presented in the first three chapters of this Progress Report covering the period from 1 January to 31 December 1982. Although part of the research within Metereology, the activities of the Test Plant for Small Wind Mills are reported in chapter four.

1. CONDENSED MATTER PHYSICS

1.1. Introduction to work in condensed matter physics

The condensed matter physics research is predominantly experimental utilizing diffraction of neutrons, x-rays, and synchrotron x-ray radiation. The neutron scattering experiments are carried out at the DR3 reactor, where the physics department operates seven spectrometers, including a new small angle scattering facility which was commissioned this year. The experiments using synchrotron x-ray radiation takes place at HASY-laboratory, at DESY in Hamburg. FRG, and they are prepared at a rotating anode x-ray source at Risø.
The research topics range from studies of structure, excitations and phase transitions in model systems to studies of ion transport, texture and recrystallization kinetics with a more applied scope. A major part of the neutron scattering work concerns magnetic materials utilizing the unique properties of the neutron as a probe for magnetism and the theoretical efforts are also centred in this field. The synchrotron and x-ray research has dealt with structures of the liquid-vapor interface of liquid crystals and monolayers on surfaces as well as technical developments of focussing crystals and samples at high pressures.
The small angle neutron scattering spectrometer is partly operated as a user-facility available to visiting scientists for structural studies in molecular biology. Otherwise it is used like other spectrometers for in-house, often collaborative, programs for studies of radiation damage, composite and porous materials, and polymers.

1.1.1. Correlation theory of planar magnets for $T \gtrsim T_c$

A selfconsistent theory for static and dynamic properties of planar magnets including quantum and correlation effects was developed. It is a generalisation of the correlation theory for one dynamical variable* (which was successfully applied to EuO and EuS) to two variables. In this case a soft mode is expected and the renormalization and damping is calculated. As a new and unexpected feature a central peak absorbing all the spectral weight near the transition temperature is found. Qualitative agreement is obtained with observations made on Pr, which approximately represents a singlet-doublet model. The correlation theory is a systematic generalization of the random phase approximation with an equally wide range of applicability. Calculations were also done for the pseudo one-dimensional system $CsFeCl_3$ for which a complete experimentel study is not yet available.

*Lindgård, P.-A. (1983). Phys. Rev. 27, 2980.

Author: (7)

1.1.2. Theory of spin waves in a sinusoidal phase

A theory of spin waves in a sinusoidal phase is developed by considering $\delta Q = Q - Q_C$ as a small parameter relative to the closest commensurate wave vector Q_C, for which the spin wave spectrum can be solved using sublattices and the random phase approximation. A second order differential equation can then be formulated and solved to yield the dispersion relation and an energy width of the modes in any incommensurate phase. The phason mode a low frequencies was not considered in this study. The theory is relevant for experiments on dynamics of incommensurate systems like Nd, Pr and $CeAl_2$.

Author: (7)

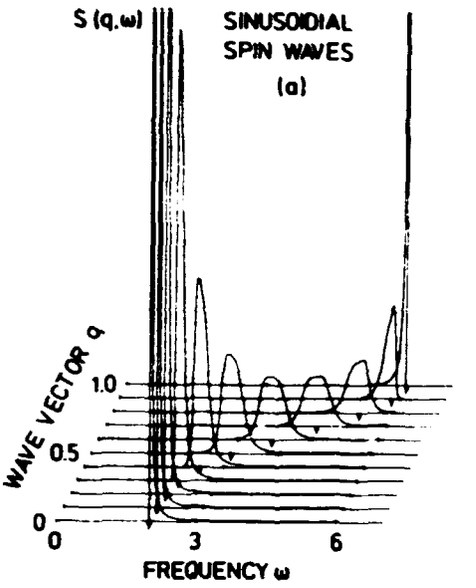

Fig. Dispersion, width and intensity of the sinusoidal spinwave mode in an incommensurate structure with $\delta Q \sim q_{zone}/50$.

1.1.3. Collective excitations in the singlet ground state dimer system $Cs_3Cr_2Br_9$

Neutron scattering experiments were performed on a single crystal of $Cs_3Cr_2Br_9$ in which the trivalent transition metal ions are strongly coupled pairwise to form magnetic dimers in $Cr_2Br_9^{3-}$ complexes. The crystal structure is hexagonal, space group $P6_3/mmc$, with two dimers per unit cell forming two sublattices. The coupling between the S=3/2 Cr^{3+} ions acts not only within the dimers (J) but also between dimers on same and different sublattices (J_p,J_c). J is negative which leads to a S=0 ground-state followed by the S=1, 2, and 3 excited states.
The magnetic dipole transitions between the two lowest states are investigated by inelastic neutron scattering. The experiments were performed on the triple-axis spectrometer TAS 7. At 1.6 K we measured the dispersion of these excitations in three different directions in the Brillouin zone. Two excitations exist for each momentum transfer corresponding to the optic and acoustic mode, respectively. Near the K-point the dispersion curves exhibit pronounced minima. A study of the temperature dependence near these minima showed typical soft mode behaviour although the softening is not complete, thus no magnetic order occcurs in this compound above 1.5 K. The dispersion relations were calculated by a Greens function method in RPA. A fit to the data yields $J = -1.01$ meV, $J_p = -0.028$ meV, and $J_c = -0.020$ meV.

Authors: (26,5,46,37)

1.1.4. Magnetic excitations in CeAs, an effective S=1/2 fcc antiferromagnet

The cerium and uranium monopnictides (CeX, UX; X=P,As,Sb,Bi) provide examples of the large family of rocksalt-structured antiferromagnets with anisotropic magnetic interactions leading to unusual magnetic properties: layered type spin structures, possible multi-$\vec{q}$ structures, and complex magnetic phase diagrams. The magnetic properties of CeAs orginate in the single 4f electron of the Ce^{3+} ion. The octahedral crystal field splits the lowest lying J-multiplet $^2F_{5/2}$ into a ground-state doublet Γ_7 and an excited quartet Γ_8 at 160 K. At $T_N \sim 8$ K antiferromagnetic type I (AF/I) ordering is observed where ferromagnetic (001) sheets are stacked in a +-sequence. The actual ordering may correspond to an alignment of the moments parallel to (001) with an ordering wave-vector $\vec{q}_o$ = (001) giving rise to a tetragonal distortion. We have performed inelastic neutron scattering measurements of the spin-wave spectrum of CeAs which considered as an effective spin one-half fcc antiferromagnet. The basically new result of the present experiments is the observation of a splitting of the spin-wave excitation into two modes of transverse polarization which exhibit quadratic dispersion and nearly zero energy-gal at the approprimate X-point in reciprocal space.

Authors: (41,5,34,60)

1.1.5. Magnetic excitations of HoP

Holmium phosphide belongs to the large class of NaCl-structured rare earth monopnictides. It orders ferromagnetically at T_C = 5.6 K with a second-order phase transition. At T_P = 4.7 K there is a first-order transition from the ferromagnetic phase to a flopside spin structure in which the f.c.c. lattice of Ho is broken up into two sublattices. The easy axis of the magnetization in the ferromagnetic phase is along <100>. HoP has a strong crystal field which exerts a large single ion anisotropy on Ho. The crystal-field parameters were determined previously by neutron spectroscopy as W = - 0.025 meV and x = 0.75 in the notation of Lea et al., i.e. the six lowest lying states of the groundstate multiplet $^5I_8$ of Ho become almost degenerate and well separated from others. The inelastic neutron scattering technique was used to measure the magnetic excitation spectrum of HoP in the flopside phase. Four spin-wave branches were found which are almost independent of wave vector. The results are analyzed in terms of a mean field Hamiltonian containing a crystal field and bilinear and quadrupolar pair interactions. On the basis of the resulting model parameters we are able to explain the magnetic behaviour of HoP, in particular the appearance of first the ferromagnetic and then the flopside phases.

Authors: (5,34,47)

1.1.6. Neutron diffraction of the magnetic structure of Er metal

Previous experiments have shown that at low temperatures there exist three kinds of magnetic ordering in Er metal in the three temperature regions 52.4 K < T < 84.4 K, 18 K < T < 52.4 K and T < 18 K. In the high temperature phase, the c-axis moments are ordered sinusoidally with the wave vector parallel to the c-axis and a period of seven atomic layers. In the low temperature phase the structure is a c-axis cone structure with a period of eight atomic layers. Our intention were to study the intermediate temperature phase where the form of the structure has not been fully described experimentally but has been described theoretically by Jensen*. His proposal is, that for a single magnetic domain, the moments describe an ellipse with the major axis close to the c-axis and the minor axis close to an a-axis ($[\bar{1}20]$ reciprocal lattice direction). The period is approximately eight atomic layers. In our experiment we looked at the intensity and positions of the magnetic Bragg-reflections with and without a magnetic field of 2.78 T in the $[\bar{1}20]$ direction as a function of temperature. The primary effect of the magnetic field was expected to be the formation of only two magnetic domains where the moments describe ellipses with the minor axes close to 60° from the applied field. The observed decreased satellite intensities do not seem to confirm the theoretical prediction.

*Jensen, J. (1976). J. Phys. F6, 1145.

Authors: (63,6,27)

1.1.7. Neutron diffraction study of the low temperature magnetic structure of hexagonal FeGe

FeGe exists in three polymorphs with cubic, hexagonal and monoclinic structures, respectively. Neutron diffraction, magnetic susceptibility, torsion and Mössbauer studies have shown that hexagonal FeGe is antiferromagnetic below 410 K with the spins predominantly along the c-axis. A detailed study by a group at Uppsala University, Sweden, using macroscopic techniques led to the proposal that below 30 K the magnetic structure is an antiferromagnetic double-cone structure, where the coupling between the basal-plane moments is ferromagnetic. Based on spin flop measurements, the critical field at 4.2 K for complete alignment of the spins along $\hat{c}$ was expected to be 1.4 T for field perpendicular to $\hat{c}$ and 7.1 T for field parallel to $\hat{c}$. The aim of the present neutron diffraction study was to find microscopic support for the above proposal. The data show that the basal-plane moments start to order at ~ 57 K and that there are two low temperature transitions, one at ~ 57 K and one at ~ 30 K. Measurements in a magnetic field indicate that although there is an abrupt decrease in the basal-plane moment for a field of 1.4 T in the basal plane, complete alignment of the spins along $\hat{c}$ is reached only at ~ 4 T. The transition at ~ 57 K is consistent with an anomaly observed in pulse magnet measurements. The neutron data may be interpreted in terms of the proposed antiferromagnetic double-cone structure below ~ 57 K.

Authors: (31,6,30)

1.1.8. Magnetic neutron scattering studies of $Cd_{1-x}Mn_xTe$

Magnetic susceptibility and specific heat studies of the diluted magnetic semiconductor $Cd_{1-x}Mn_xTe$ have shown that for $x < 0.17$ the system is paramagnetic, for $0.17 < x < 0.60$ the system exhibits spin glass properties and for $0.60 < x < 0.71$ the system shows antiferromagnetic like ordering. For $x < 0.71$ the structure is a homogeneous zinc-blende structure, and unlike most spin glasses, there are no competing magnetic interactions, but only short-range antiferromagnetic interactions. Elastic neutron scattering studies on single crystals with $0.60 < x < 0.71$ have shown Lorentzian-like maxima at low temperatures consistent with type III antiferromagnetic ordering of the f.c.c. magnetic sublattice. Computer calculations of the elastic neutron scattering cross-section and some other quantities characterising the system has been carried out using a Monte Carlo modelling method and published data on the exchange interactions in $Cd_{1-x}Mn_xTe$. Preliminary calculations are able to reproduce the Lorentzian-like magnetic peaks observed experimentally. Measurements of the inelastic scattering in $Cd_{0.35}Mn_{0.65}Te$ revealed broad maxima in the scattered spectra which can be related to the results of Raman scattering experiments and existing theories of the spin dynamics in related systems ($Zn_{1-x}Mn_xTe$).

Authors: (36,6,24,43,35)

1.1.9. Neutron diffraction studies of some transition metal salts of saturated fatty acids

Saturated fatty acids are a large group of aliphatic carboxylic acids of the empirical formula $C_nH_{2n}O_2$, where n may be any even or odd integer. Transition metal salts of many such acids are widely used in the chemical industry, but only recently they have attracted scientific attention because of their novel magnetic properties. These are due to a predominantly two-dimensional character, which comes about because both the fatty acids and the salts of fatty acids have a layer structure, where the magnetic ions are situated in layers separated by long hydrocarbon chains. We have studied powders of several deuterated salts containing Mn, Fe and Ni by means of neutron scattering in a search for long range magnetic ordering. Down to 0.8 K, we neither observed Bragg peaks arising from three- nor from two-dimensional ordering. However, in Mn-sterate we did observe increased scattering at low angles. In the samples studied, the inter layer distances vary between 30 to 50 Å, which allows quite a few of the successive orders of reflections to be observed. In deuterated Mn-sterate, we observed up to (0,0,20). We expect that the intensities of the various reflections can be used to give information about the location of those COOH groups where in the salts, the hydrogen atoms are replaced by transition metal atoms.

Authors: (54,6,53)

1.1.10. Crystal structures from first principles calculations

The crystal structures of the elemental metals tend to occur in certain sequences, both as a function of atomic number and as a function of pressure. Most celebrated in this respect are the hcp → Sm-type → dhcp → fcc and the hcp → bcc → hcp → fcc sequences observed in the rare earth and the transition metal series, respectively. Pettifor has recently explained these two sequences on the basis of canonical band calculations and established a correlation between crystal structure and d electron occupation number. As a function of pressure the alkaline earths exhibit the sequence fcc → bcc → hcp which cannot be explained within canonical band theory. Therefore we have performed fully hybridized and self-consistent band calculations for the IIA metals including also Eu and Yb, and evaluated the structural energy differences by means of the so-called force theorem. The theory explains the crystal structures of the alkaline earth metals observed over a wide pressure range, and the present approach is now being extended to most other metals.

*Work supported by the Danish Natural Science Foundation.

Authors: (28,42,29)

1.1.11. Neutron scattering and specific heat studies of disorder in pure flourite ionic conductors

The anion disorder in the fast-ion phase of the fluorites has been studied using data from neutron diffraction (PbF_2, CaF_2 and $SrCl_2$), coherent diffuse quasielastic neutron scattering (PbF_2, CaF_2 and $SrCl_2$) and from specific heat measurements (PbF_2). The diffuse scattering revealed characteristic short range correlations between the disordered anions, and an instantaneous picture of the disorder can be visualized as an assembly of small non-interacting defect clusters. In simple models these defect clusters consist of one or two true interstitials plus relaxation of the nearest neighbour anions - so-called 2:1:2 and 2:2:2 clusters. The relaxation is of the order of one anion radius, and hence it is subject to discussion whether to count both the true interstitials and the relaxed anions as interstitials. The best representation of the diffraction results was obtained by a model where the relaxed ions were considered as interstitials rather than anions with large anharmonic vibrations, and the derived thermally generated defect concentrations (true interstitials + relaxed ions) were 14-25% at T_c raising to 30-50% close to the melting temperature. These values are in good agreement with estimates based on a) a simple phenomenological mean-field thermodynamic model calculation of the specific heat of PbF_2, and b) the observed absolute intensity of the diffuse scattering.

Authors: (25,4,5,40,38,33,55,59)

1.1.12. Neutron scattering, ionic conductivity, and specific heat studies of heavily doped fluorite ionic conductors

The process of ionic conduction in a solid is only possible in the presence of disorder. Crystals with the fluorite (CaF_2-structure) have been proven to be highly accessible to the formation of defects, both by thermal generation and by doping with excess charge cation fluorites. Quasielastic neutron scattering measurements have been used to study the defect structure of $Ba_{1-x}La_xF_{2+x}$ and $Ba_{1-x}U_xF_{2+2x}$ at room temperature. The results have been analysed by use of model calculations based on the so-called 222- and 212-cluster defects*, respectively, and satisfactory agreement has been obtained. In $Ba_{1-x}la_xF_{z+x}$ tendencies towards ordering of the clusters in more extended aggregates have been observed below 800°C, and the short range correlations between the defect components have been shown to reduce the ionic conductivity. The thermal formation of defects in $Ba_{1-x}La_xF_{2+x}$ and $Pb_{1-x}U_xF_{2+2x}$ have been studied by specific heat measurements. The data on $Pb_{1-x}U_xF_{2+2x}$ have been analysed by means of a simple phenomenological mean field thermodynamic model calculation, and the results have been used to deduce the thermally generated defect concentrations.

*See 1.1.11.

Authors: (4,25,5,56)

1.1.13. Structural disorder in fast ionic conducting α-phase-Li_2SO_4 studied by neutron scattering on single crystals

Alkaline sulphates have high temperature cubic α-phases which have ionic conductivities characteristic of a fast ionic phase. x-ray and neutron powder diffraction studies based on 4 to 5 lines of Li_2SO_4 have established confidence to a structural model which allows the translational lithium diffusion via interstitial sites on the body diagonals of the f.c.c. structure, strongly mediated by a rotational disorder in the sulphate groups. In order to improve on the experimental diffraction data and to study more closely the observed diffuse quasielastic scattering, a technique of growing single crystals of α-phase-Li_2SO_4 on a spectrometer has been developed. Diffraction intensities of some 20 lines were recorded. The diffuse quasielastic scattering turned out to be almost isotropic and could be reasonably reproduced by a model calculation based on the correlation imposed by the rigid configuration of the sulphate groups. Tendencies towards more extended correlations were observed, possibly related to the so-called "paddle-wheel mechanism" by which the sulphate groups are suggested to mediate the lithium diffusion. The temperature dependence of the energy width of the diffuse scattering support that the sulphate groups rotate almost freely.

Authors: (4,5,51)

1.1.14. Deuterium short range order in a PdAgD alloys studied by diffuse neutron scattering

The relative roles of the deuterium density and of the ensuring changes in the overall electronic structure has been studied by diffuse neutron scattering of the D short range order in $Pd_{0.975}$ $Ag_{0.025}$ $D_{0.685}$. Single crystal samples were investigated at temperatures of 50 K and at 70 K. The results were compared to short range order in the PdD_x system and it was shown that the iso-intensity contours at (1/2,1,0) are similar to those observed in $PdD_{0.71}$. This indicates that the characteristic changes in the short range ordering which occur near x=0.7 in PdD_x originate in the electronic structure rather than being directly related to the deuterium density.

Authors: (5,32)

1.1.15. Recrystallization kinetics for pure copper

The newly developed neutron texture-goniometer has been used for in-situ studies of the recrystallization in heavity deformed (cold-rolled to 95% reduction in thickness) pure copper. The temporal evolution of specific characteristic texture-components was followed during isothermal annealing with a time resolution in the order of seconds. The results were analysed by an Avrani model, and it was found that the growth-rate is a constant independent of the time. This indicates that the new recrystallized grains either grow as needles, or that they, very fast, grow to a limiting size, where the process stops. Electron microscopy observations support the second interpretation, so it is concluded that the recrystallization is determind by nucleation rather than growth of the nuclei. This result is valid for all texture components studied, and for copper materials with different mean grain sizes before deformation.

Authors: (10,5,45)

1.1.16. Computer program for quantitative texture analysis

The texture of a polycrystalline material is completely described by a three dimensional orientation distribution function (ODF) defined as the intensity function representing the distribution of the different crystallite orientations in the sample. Direct measurements of the ODF for a polycrystalline material are not possible with standard techniques. However, the orientation distribution of a particular crystallographic plane can be determined by difffraction experiments, and visualized in terms of pole figures. By correlating pole figures for different planes the ODF can be synthesised mathematically (Bunge*). A computer program which applies this technique, has been developed. The program transfers the pole figure data, measured at the neutron-diffraction texture goniometer at Risø, into ODF's. At the present stage the program is capable of calculating the ODF for sheet samples of cubic crystal symmetry.

*Bunge, H.J. (1969), Mathematische Methoden der Texturanalyse, Akademie Verlag, Berlin.

Author: (10)

1.1.17. Synchrotron x-ray diffraction on the adsorbed monolayers of rare gases and simple molecules on graphite surfaces

At the three axis spectrometer at the storage Ring DORIS at DESY, Hamburg we have studied the following systems: N_2 monolayers and monolayer mixtures of Xe with Ar, Kr, CH_4 or CF_4. At the storage ring SPEAR at SLAC in Stanford, USA the two dimensional melting transition of Ar monolayers was studied.
In the N_2 layers we identified the uniaxial transformation connected with the commensurate-incommensurate phase transition and found a new nontriangular two dimensional phase at higher temperatures. The binary system were studied with the primary goal of studying order disorder phase transitions but so far none of the systems have been found to order chemically. However, in the Xe + Cf_4 system a new phase has been found at low temperature and dilute CF_4 concentration characterized by an unusual broad structure factor.

Authors: (11,9,1,8,48,49)

1.1.18. Structure and phase transitions of the liquid-vapour interface of liquid crystals by synchrotron x-ray diffraction

At the free surface of a liquid crystal there is a strong tendency or "field" to form smectic layers even in the nematic phase. As the temperature is lowered towards the bulk transition to the smectic-A phase the liquid crystal becomes more susceptible to this field and consequently the layering penetrates deeper into the nematic phase. We have determined the "field" as well as the penetration depth by comparing the diffracted intensity from the surface layering to the Fresnel diffraction at smaller angles due to the discontinuity in x-ray index of refraction of liquid and vapour. In addition we observe interesting interference phenomena of the two types of diffracted waves. The results will be published in 1983.

Authors: (1,52)

1.1.19. Diffuse synchrotron x-ray scattering from AgBr near the melting point

Experiments on tracer diffusion specific heat and ionic conduction of AgBr near its melting point (425°C) indicate an unusual high concentration (~ several per cent) of Frenkel defects. Direct evidence of this phenomenon can in principle be obtained from diffuse x-ray scattering. The defects produce long-ranged distortions of the lattice which in turn give rise to so-called Huang-tails to the Bragg peaks. One problem for such a study of AgBr is the x-ray absorption (1/e length ~ 10 μ at 1.54 Å). However, by using a wavelength of $\lambda = 0.25$ Å, which indeed is practical at DORIS operating at 5 GeV, a crystal thickness of 0.2 mm can be used in transmission. The necessesary resolution can be obtained by using a triple axis spectrometer with perfect crystals as monochromator and analyser. Our initial study indicates that this sort of experiments may be possible although we have not yet obtained data for the Huang scattering. One obstacle, but on the other hand an interesting phenomenon, turned out to be recrystallization of the AgBr crystal upon heating from an essentially contineous distribution of crystallite orientations over a range of several hundred milli-degrees at room temperature to a few crystallites 15°C below the melting point.

Authors: (1,11,38)

1.1.20. High pressure research using synchrotron x-ray radiation

Methodical problems of high pressure research with synchrotron radiation using diamond anvil cells and x-ray diffraction techniques have been surveyed. The main limitations imposed on diffraction experiments by high pressure cells are: (i) absorption by the cell of the incident and diffracted beams (ii) limitations in the scattering angle, and (iii) the small cross section and the small volume of the sample. In view of these limitations the merits of energy-dispersive and angle-dispersive diffraction have been compared. Among some of the special features of synchrotron x-ray radiation, it turned out that for energydispersive diffraction, the high brightness is important, while for angle-dispersive diffraction it is the high brilliance which is important. In the first case multipole wrigglers shifting the incident spectrum and/or increasing the brightness enable the production of the required spectrum for a given experiment. In the second case multipole wigglers and undulators enable the choice of the most suitable wavelength for a given experiment.

Author: (24)

1.1.21. Small angle neutron scattering

The small angle neutron scattering (SANS) spectrometer was completed and the first biological experiments were carried out in the fall of 1982. Auxilliary equipment such as a Peltier-cooled sample changer, and adapters for cryostats and magnets have been manufactured. A comprehensive control program for the PDP-11 computer control system has been developed. The absolute neutron flux was determined in the wavelength range 3-25 Å and it was found to match the design estimates.
The structure of alpha-2-macroglobulin has been studied with systematic variation of H_2O/D_2O contrast and concentration. The results for pure H_2O agree with those obtained by small angle x-ray scattering whereas additional structure is found at low angles for the D_2O rich solutions. The analysis of these spectra is not yet completed.
Preliminary studies of radiation damage in thin Al-foil have been performed. Specimens irradiated by neutrons in DR3 were studied in the momentum range $0.003\ Å^{-1} < q < 0.15\ Å^{-1}$. The samples were in the shape of stacked disc's of 3 mm diameter and a total thickness of 0.5 mm and has been exposed to the total fast neutron dose of $1x10^{20}\ n/cm^2$ at 120°C. The SANS spectra were analysed in terms of a distribution of void sites and good overall agreement was found with the results obtained by transmission electron microscopes. Similar experiments were performed on proton (600 MeV) irradiated samples from SIN, Switzerland. The analysis of these results are in progress.

Authors: 3,5,57,58,62)

1.1.22. The four-circle neutron diffractometer

The four-circle neutron diffractometer has been used to collect the necessary data to solve several crystallographic problems. In addition it has been widely used to orient crystalline samples. Risø personel has mainly used the diffractometer to collect data at room temperature on LaF_3, PrF_3, NdF_3 and $La_{1-x}Ba_xF_{3-x}$ ($x = 0.104$). A group from the Chemical Institute, University of Århus, Denmark has used the diffractometer extensively to solve more chemically oriented crystallographic problems. In a study of U_4O_9 data was collected at ambient temperature and above using a heating system where the sample is heated by a jet of hot air. With a distance of 1 cm between the sample and the "hot-air-blower" the sample temperature could be varied from ambient temperature up to 300°C and kept constant within 1°C.
Major parts of the Fortran 77 crystallographic data analysis system developed at the Chemical Institute, University of Århus have been implemented at the Risø B-7800 main computer.

Authors: (6,50,44,39,61)

1.1.23. Liquid N_2 and He plant

The delivered quantities of liquid N_2 and He amounted to 17,5000 and 16,000 litres, respectively. Out of these amounts 7,000 litres of liquid He were delivered to laboratories in Copenhagen, Odense, and Aarhus.

Authors: (16,14,8)

1.2. Participants in the work in condensed matter physics

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1. Als-Nielsen, J. (1.1.17,1.1.18,1.1.19)
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26. Feile, R. (1.1.3)	(Risø grant)
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**Supported by the Danish National Science Foundation

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64. Mulvad, Karsten (Technical University of Denmark)

1.3. Publications and educational activities

1.3.1. Publications

ALS-NIELSEN, J., CHRISTENSEN, F. and PERSHAN, P.S. (1982). Smectic-A order at the surface of a nematic liquid crystal: Synchrotron X-ray diffraction. Phys. Rev. Lett. 48, 1107.

ALS-NIELSEN, J., PERSHAN, P.S., SCHNOPPER, H.W., SILVER, E.H., and WESTERGAARD, N.J. (1982). New crystal for 200-1200 eV soft X-ray spectroscopy. Appl. Optics 21, 1894.

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BURAS, B. (1982). High pressure research with synchrotron radiation. University of Copenhagen, Physics Laboratory II, Report No. 82-08, 11 pp and Deutsches elektron-Synchrotron DESY SR-82-83 11 pp.

BURAS, B., BJERRUM MØLLER, H. and ALS-NIELSEN, J. (1982). Kæmpechance for det danske forskningsmiljø. Forskning og Samfund 8, 19 (February).

BURAS, B. and LEBECH, B. (1982). Nyt fantastisk "lys". Naturens Verden 4, 155.

BOULET, R.M., JAN, J.-P. and SKRIVER, H.L. (1982). De Haas-van Alphen effect and LMTO bandstructure of $LaSn_3$. J. Phys. F12, 293.

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CLAUSEN, K. and LEBECH, B. (1982). Magnetic excitations in Ho_2Co_{17} and Ho_2Fe_{17}. J. Phys. C15, 5095.

COLLETT, J., SORENSEN, L.B., PERSHAN, P.S., LITSTER, J.D., BIRGENEAU, R.J. and ALS-NIELSEN, J. (1982). Synchrotron X-ray study of novel crystalline-B phases in heptyloxybenzylideneheptylaniline (70.7). Phys. Rev. Lett. 49, 553.

FEILE, R., LOIDL, A. and KNORR, K. (1982). Elastic properties of $(KBr)_{1-x}(KCN)_x$. Phys. Rev. B26, 6875.

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STEINER, M., KAKURAI, K., KNOP, W., PYNN, R. and KJEMS, J.K. (1982). Neutron inelastic study of transverse spin fluctuations in $CsNiF_3$: A soliton only central peak. Solid State Commun. 41, 329.

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1.3.2. Conference contributions

ALS-NIELSEN, J. Structure of surfaces by X-ray diffraction. Workshop on Applications of Synchrotron Radiation to Condensed Matter Physics, NORDITA, Copenhagen (August).

ALS-NIELSEN, J. Synchrotron X-ray diffraction study of liquid surfaces. International Conference on X-Ray and VUV Synchrotron Radiation Instrumention, DESY, Hamburg, F.R.G. (August).

ALS-NIELSEN, J. The X-ray scientific case for a european synchrotron radiation facility. International Conference on X-Ray and VUV Synchrotron Radiation Instrumentation, DESY, Hamburg, F.R.G. (August).

ALS-NIELSEN, J., BOHR, J., KJÆR, K., NIELSEN, M., LAUTER, H.J. and McTAGUE, J.P. Treffen der Nützer der Synchrotronstrahlung und Neuer Interessenten, DESY, Hamburg, F.R.G. (January).

BOHR, J. Smeltning af to-dimensionale film på grafit. En kontinuert smeltning. 18. danske Krystallografmøde, Risø, (May).

BOHR, J. and KJÆR, K. Use of a position sensitive detector for data acquistion of synchrotron X-ray diffraction from adsorbed monolayers. International Conference on X-Ray and VUV Synchrotron Radiation Instrumentation, DESY, Hamburg, F.R.G. (August).

BOHR, J., NIELSEN, M., McTAGUE, J.P., ALS-NIELSEN, J. and KJÆR, K. Synchrotron X-ray study of physisorbed films of mixtures of Ar and Xe on graphite. Danish Physical Society, Spring Meeting, Nyborg Strand (May).

BOHR, J., NIELSEN, M., McTAGUE, J.P., ALS-NIELSEN, J. and KJÆR, K. Synchrotron X-ray study of physisorbed films of mixtures of Ar and Xe on graphite. Second Trieste International Symposium on Statistical Mechanics of Adsorption, Trieste, Italy (July).

BURAS, B. High pressure research with synchrotron radiation. International Conference on X-ray and VUV Synchrotron Radiation Instrumentation, DESY, Hamburg, F.R.G. (August).

BURAS, B. Structure of solids under high pressure. Workshop on Applications of Synchrotron Radiation to Condensed Matter Physics, NORDITA, Copenhagen, (August).

BURAS, B. Diffraction from moving and vibrating crystals. International Conference on the 50th Anniversary of the Discovery of the Neutron: The Neutron and its Applications, Cambridge, U.K. England, (September).

BURAS, B. High pressure research with synchrotron radiation. Workshop on Synchrotron Radiation and High Pressure Studies, Cornell University, Ithaca, USA. (October).

CLAUSEN, K. and LEBECH, B. Magnetic excitations in Ho_2Co_{17}. and Ho_2Fe_{17}. International Conference on Magnetism, Kyoto, Japan (September).

HESSEL ANDERSEN, N., CLAUSEN, K., KJEMS, J.K. and SCHOONMAN, J. Neutron scattering, ionic conductivity and specific heat studies of the ionic conductors. $Ba_{1-x}La_xF_{2+x}$ (x = 0.209, 0.492). Danish Physical Society, Topical Meeting on Physical Properties of Disordered Systems, Technical University of Denmark (October).

HESSEL ANDERSEN, N., POULSEN, F.W. and EICHINGER, G. Conductivity, structure and specific heat of $LiBiO_2$. Second European Conference on Solid State Chemistry, Veldhoven, The Netherlands (June).

JUUL JENSEN, D., KJEMS, J., LEFFERS, T. and HANSEN, N. Apparatus for dynamical texture measurements by neutron diffraction using a position sensitive detector. Spring School on Neutron Scattering for Texture Studies of Materials, Wehlen, G.D.R. (March).

JUUL JENSEN, D., KJEMS, J., LEFFERS, T. and HANSEN, N. Investigation of recrystallization kinetics using a fast in-situ measuring technique. Danske Krystallografmøde, Risø (May).

KJEMS, J.K., HESSEL ANDERSEN, N., CLAUSEN, K. and SCHOONMAN, J. Neutron scattering study of the disordered $La_xBa_{1-x}F_{2+x}$. Danish Danish Physical Society, Spring Meeting, Nyborg Strand (May).

KJEMS, J.K., CLAUSEN, K., HESSEL ANDERSEN, N. and SCHOONMAN, J. Structure and dynamics of disordered solids: A neutron scattering study of $Ba_{1-x}La_xF_{2+x}$. Yamada Conference, Hakone, Japan (September).

KJEMS, J.K., KAKURAI, K. and STEINER, M. Neutron scattering study of spin fluctuations in $CsNiF_3$ without applied field. International Conference on Magnetism, Kyoto, Japan (September 1982).

KJÆR, K., NIELSEN, M., BOHR, J., McTAGUE, J.P. and LAUTER, H.-J. Synchrotron X-ray study of submonolayers of CF_4 on graphite. Second Trieste International Symposium on Statistical Mechanics of Adsorption, Trieste, Italy (July 1982).

LEBECH, B., NIELSEN, L., HAZELL, R.G. and NEVALD, R. The crystal structure of NdF_3. 18. Danske Krystallografmøde, Risø (May).

LEBECH, B., HESSEL ANDERSEN, N., STEENSTRUP S. and SCHRØDER PEDERSEN, A. The structure of ytterbium-dihydride. 18. Danske Krystallografmøde, Risø (May).

LINDGÅRD, P.-A. Theory of excitations in the 1-d singlet ground state magnet $CsFeCl_3$. Sixth Yamada Conference, Hakone, Japan (September).

LINDGÅRD, P.-A. Theory of singlet doublet systems showing a soft mode and a central peak. International Conference on Magnetism, Kyoto, Japan (September).

LINDGÅRD, P.-A. Theory of spin waves in a sinusoidal phase. International Conference on Magnetism, Kyoto, Japan (September).

MACKINTOSH, A.R. Neutron scattering and magnetism. International Conference on the 50th Anniversary of the Discovery of the Neutron: The Neutron and its Applications, Cambridge, U.K., (September).

McEWEN, K.A., LEBECH, B. and VETTIER, C. Uniaxial stress dependence of the magnetic structure of neodymium. International Conference on Magnetism, Kyoto, Japan (September).

MOON, R.M., THOMPSON, J.R. and LEBECH, B. Sublattice Susceptibility and low temperature magnetic phases of neodymium. International Conference on Magnetism, Kyoto, Japan (September).

NIELSEN, L. and LEBECH, B. Progress in the study of the detailed structure of PrF_3 and NdF_3 by neutron diffraction, F-NMR and Pr-NMR. Danish Physical Society, Spring Meeting, Nyborg Strand (May).

NIELSEN, M. Pressure driven commensurate-incommensurate transition in krypton monolayers. Second General Conference of the Condensed Matter Division of the EPS, Manchester, U.K. (March).

NIELSEN, M. Melting and commensurate-incommensurate transition in physisorbed monolayers. Danish Physical Society Annual Meeting at Risø, (November).

NIELSEN, M. Phase transitions in two dimensional films. Workshop on Applications of Synchrotron Radiation to Condensed Matter Physics, NORDITA, Copenhagen (August).

NIELSEN, M., ALS-NIELSEN, J., BOHR, J. and McTAGUE, J.P. Pressure-driven commensurate-incommensurate transition in low-temperature sub-monolayer krypton on graphite. Treffen der Nützer der Synchrotronstrahlung und Neuer Interessenten, DESY, Hamburg, F.R.G. (January).

NIELSEN, M., BOHR, J. and KJÆR, K. Physisorbed Monolayer on Graphite Studied by Neutron and X-Ray Diffraction. Third International Conference on Vibrations at Surfaces, Asilomar, California, USA. (September).

NIELSEN, M., BOHR, J. and KJÆR, K. Diffraction measurements on physisorbed films. International Conference on the 50th Anniversary of the Discovery of the Neutron: The Neutron and its Applications, Cambridge, U.K. (September).

NIELSEN, M., BOHR, J., KJÆR, K., ALS-NIELSEN, J. and McTAGUE, J.P. Synchrotron X-ray diffraction applied to the study of physisorbed monolayers. International Conference on X-ray and VUV Synchrotron Radiation Instrumentation, DESY, Hamburg, F.R.G. (August).

SKRIVER, H.L. Cohesion and electronic structure of the actinide metals. Second General Conference of the Condensed Matter Division of the EPS, Manchester, U.K. (March).

SKRIVER, H.L. The alkaline earths under pressure. 1982 Gordon Conference on Physics and Chemistry at High Pressure, meriden, USA. (July).

SKRIVER, H.L. Electronic structure and cohesion in the rare earth metals. NATO Summer School on the Systematics and the Properties of the Lanthanides, Braunlage, F.R.G. (July).

SKRIVER, H.L. Crystal structures under pressure from first principles calculations. European High Pressure Physics Conference, Stuttgart, F.R.G. (August).

STAUN OLSEN, J., BURAS, B., GERWARD, L., JOHANSSON, B. LEBECH, B., SKRIVER, H. and STEENSTRUP, S. Structural transformations of YbH_2 induced by high pressure. 18. Danske Krystallografmøde, Risø (May).

STEINER, M., KAKURAI, K. and KJEMS, J.K. Inelastic neutron scattering studies of nonlinear excitations in the 1-D ferromagnet $CsNiF_3$ under an applied field. Sixth Yamada Conference, Hakone, Japan (September).

WULFF, M., JENSEN, J., MACKINTOSH, A.R., BJERRUM MØLLER, H., McMASTERS, O.D. and GSCHNEIDNER, K.A. Jr. Excitations of neodymium ions in praseodymium. International Conference on Magnetism, Kyoto, Japan (September).

1.3.3. Lectures

ALS-NIELSEN, J. Liquid crystals, perfect crystals and perfect, liquid crystals.
1) Max Planck Institute, Stuttgart, F.R.G. (January)
2) Harvard University, Cambridge, Massashusetts, U.S.A. (March)
3) Fysisk Forening, Niels Bohr Institute, Copenhagen (April)
4) Hahn Meitner Institute, Berlin (May).

ALS-NIELSEN, J. Det Europæiske Synchrotron Forskningscenter - ved Risø?
1) Risø colloqium (February)
2) Roskilde Universitets Center (May).

ALS-NIELSEN, J. Synchrotronstråling og dens anvendelser i fysik. University of Oslo, Norway (February).

ALS-NIELSEN, J. The scientific case for a European synchrotron. SERC, Council Meeting, Daresbury, U.K. (September).

ALS-NIELSEN, J. Statusbericht HASYLAB: Röntgenspektroskopie. Wissenschaftlichen Rates von DESY, DESY, Hamburg, F.R.G. (October).

BAUER, R. Det katalytisk aktive zink center i zink enzymer belyst ved hjælp af ^{111}Cd-γ-coincidens spektroskopi. University of Odense, Denmark (October).

BJERRUM MØLLER, H. Hyperfine interactions and ordering in praseodymium. Brookhaven National Laboratory, New York, USA. (June).

HESSEL ANDERSEN, N., Neutron Scattering, ionic conductivity and specific heat studies of $Na_{1-x}La_xF_{2+x}$. State University of Utrecht, Utrecht, The Netherlands (October).

KJEMS, J.K. Crystal field splittings and superconductivity in $RE_xLa_{1-x}Al_2$. Tohuku University, Sendai, Japan (September).

KJEMS, J.K. Prospects and problems for ion transport in solids. Chalmers University, Göteborg, Sweden (October).

LINDGÅRD, P.-A. Soft mode and central peak in Pr. Institute Laue-Langevin, Grenoble, France (March).

LINDGÅRD, P.-A. Calculation of static and Dynamic Properties in paramagnetic phases.
1) Laboratoire Louis Néel, CNRS, Grenoble, France (March).
2) IBM Laboratories, Zürich, Switzerland (April).

LINDGÅRD, P.-A. Correlation theory for Heisenberg and singlet doublet systems.
1) Kyushu University, Fukuoka, Japan (September)
2) Sendai University, Sendai, Japan (September).

LINDGÅRD, P.-A. Theory of the disordered state of singlet doublet systems. Danish Physical Society, Topical Meeting on Physical Properties of Disordered Systems, Technical University of Denmark (October).

LINDGÅRD, P.-A. Theory of singlet-doublet systems. Hahn Meitner Institute, Berlin (October).

NIELSEN, M. Uniaxially incommensurate phases in monolayers of CF_4 and N_2. University of Washington, Washington, USA. (August).

2. PLASMA PHYSICS

2.1. Introduction to work in plasma physics

During 1982 the scientific programme included the following main objects:

2.1.1-2.1.9. A study of pellet-plasma interaction with the aim of assessing possibilities of refuelling a fusion reactor by shooting deuterium-tritium pellets into the plasma. The study is divided into the following sub-sections:

2.1.1-2.1.2. A detailed experimental and theoretical study of the interaction between charged particles of various energies and solid hydrogen and deuterium.

2.1.3-2.1.4. A direct investigation of the interaction between pellets and a plasma performed in the tokamak "Dante".

2.1.5. Pellet handling, acceleration, and injection.

2.1.6-2.1.9. Theoretical considerations concerning pellet ablation in hot plasmas.

2.1.10. The construction of a single point Thomson scattering for JET carried out under a contract with JET.

2.1.11-2.1.22. A study of the fundamental physics of plasmas including theoretical as well as experimental investigations of wave propagation properties, instabilities, solitons, turbulence, etc. These investigations also include studies related to electron cyclotron resonant heating of tokamak plasmas.

2.1.1. Erosion of solid H_2, D_2 and HD by electrons up to 3 keV

The work on solid H_2, D_2 and HD was extended. The gold substrate utilized in (Børgesen and Sørensen, 1982) was replaced by a carbon substrate, and no major discrepancies in the erosion rate for thick films were observed. Thick films of para-H_2 were eroded as well, and in spite of the completely different heat of conduction (differing by a factor of about 30) the yields from these films were almost identical to yields from ordinary hydrogen films. Results obtained with a new set-up with an oscillating quartz crystal monitor have largely confirmed the previously obtained results. The time for erosion measurements will decrease substantially with this new set-up.

Børgesen, P. and Sørensen, H. (1982). Phys. Lett. 90A 319-322.

Authors: (16,12,13)

2.1.2. Charged particle erosion of solid rare gases and dilute rare gas alloys. Experiment and theory

We obtained the first experimental results on electron-induced erosion of solid neon. The measurements were interpreted qualitatively within a new model invoking excitation transport by free excitons and their subsequent decay at the surface. The model accounts for the magnitude of the observed yield and the energy dependence. A theoretically predicted decrease in the erosion yield due to doping with a heavier rare gas, in casu argon, has been observed experimentally. The strong influence of very small amounts of different types of impurities makes sample purity a crucial problem in investigations of the erosion of solid rare gases.

Authors: (16,12,13,35)

2.1.3. DANTE (Danish Tokamak Experiment)

The pellet injector for the small pellets of frozen deuterium is working properly (the shape of the pellets is cylindrical, with a diameter and length of 0.4 mm). These pellets are completely ablated in the plasma, giving the possibility or measurement of the ratio between ionized material and emitted H_α-light. The theoretical value for this ratio (Johnson and Hinnov 1973) is about 20 for the plasma parameters of DANTE, but the experimental value measured on DANTE is about 40, in reasonable agreement with the experimental value obtained at ISX-B (Milora et al. 1980). Measurements of the electron temperature of the plasma by soft x-ray pulse height analysis are very delicate in Dante because of the low temperature, giving very low-energy x-rays. These are highly absorbed in the window between the plasma chamber and the detector. To improve these measurements, the Be-window in front of the detector has been removed, and a new efficiency curve in the low-energy region is being established. Experiments to investigate the possibility of heating the plasma by electron cyclotron resonance heating (ECRH) is planned in the near future. The parameter regions in DANTE for plasma density and toroidal field have been investigated because these parameters are important for the access of microwaves into the plasma.

Johnson, L.C. and Hinnov, E. (1973). J. Quant. Sectrosc. Radiat. Transfer 13, 333-358.
Milora, S.L. et al. (1980). Nucl. Fusion 20, 1491-1514.

Authors: (2,15,4)

2.1.4. Measurements of the pellet size using a microwave-cavity detector

To measure the actual size of the pellets that are injected into DANTE they pass a microwave-cavity with resonance frequency around 9 GHz. The shift in resonance frequency introduced by the pellet is proportional to the mass of the pellet*. The previously employed detector system has been modified by replacement of extensive microwave equipment with a Gunn-diode as the oscillating part of the arrangement. Using a spectrum analyzer as a detector, this equipment has been used to measure the size of the small pellets. These results are in good agreement with measurements using a destructive method in which the pellets are evaporated in a known volume.

*Jensen, P.B. and Andersen, V. (1982). J. Phys. DIS, 785-793.

Authors: (2,15,4)

2.1.5. Pellet handling and acceleration

The deuterium pellet injector system for TFR (CEN Fontenay-aux-Roses, Paris) was completed and tested. The data for the injector are:

nominal pellet size:	2.3 mm long, 0,6 mm diam.
pellet size:	8.10^{18} molecules
pellet velocity	640 m/s±60 m/s
delay after firing pulse:	3-5 ms
nylon guide tube:	2 mm inner diam. 4-5 m long,
spread in direction at TFR:	±1°
3 minutes between firings	

The injector system was mounted at the mock-up of TFR in October. It is planned that it should be moved to the TFR in February 1983.
A new pellet injector is under construction, and an injector for large pellets made by means of a larger cryostat is planned. The injector for 2 mm pellets was reconstructed for testing a different acceleration principle using a magnetically stabilized high pressure electrical discharge behind the pellet as the driving force. Preliminary tests of this principle with plastic pellets of 10 mg at room temperature conditions have produced velocities above 1 km/s. With proper temperature control of the electrical connections at cryogenic conditions, this acceleration principle may produce 1 mg D_2 pellets at velocities above 2 km/s. Currently, a rail gun accelerator, modified by a rail coil construction for increasing the driving magnetic field, was tested.

Authors: (1,21,25,26,29,13,14)

2.1.6. The effect of dissociation on the ablation rate of a hydrogen pellet

A computational code studying the effect of dissociation on the ablation of a refuelling pellet was written. The code includes the following: effect of dissociation, lowering of the ablatant temperature, change of the average molecular weight, and the ratio of specific heats.

Author: (3)

2.1.7. Rate coefficients of electronic excitation and ionization of hydrogen atoms

Available analytical expressions of the rate coefficients of electronic excitation and ionization of hydrogen atoms suitable for numerical computations were examined and compared. Existing errors were discovered and corrected.

Authors: (3,19)

2.1.8. H_α-line emission model

By neglecting the recombination effect, a simplified collisional-radiative model (C-R model) for studying the H_α-line emission from the ablatant of a refuelling pellet was formulated. A computational code suitable for studying the effect of the cut-off level was written.

Authors: (3,19)

2.1.9. Correlation between the H_α-line emission rate and the ablation rate of a refuelling pellet

By incorporating the simplified C-R model into the neutral-shielding model of Parks and Turnbull (1978), the correlation between the H_α-line emsision rate and the pellet ablation rate was studied. A computational code including two alternative modes of pellet-plasma interaction was written - the background plasma was either unperturbed or was cooled adiabatically by the pellet.

Parks, P.B. and Turnbull, R.F. (1978). Phys. Fluids 21, 1735-1741.

Authors: (3,19)

2.1.10. Single point Thomson scattering system for JET

During the past year, the ruby laser was delivered. The performance of the laser was thoroughly tested and was found to exceed specifications in all respects. It has been decided that delivery of the system to JET will be in two phases. The first delivery will contain all components associated with the torus vacuum chamber and the laser beam path, and is expected to take place in March 1983. The remaining equipment is scheduled to be ready in July 1983.
Work has been carried out to determine the scattered spectrum, including all relativistic terms. We have found a solution that reduces the problem to a number of simple single integrals that may be evaluated on the computer. In the special case of $T_e<5$ keV and collection of the dominant polarization, the result is analytical (Selden 1980).

Selden, A.C. (1980). Phys. Lett. 79A, 405-406.

Authors: (9,17)

2.1.11. Electron cyclotron wave experiment

A prospective tokamak fusion reactor must have a high β-value in order to have a sufficient efficiency. However, if the density in the centre of the plasma is too high compared to the magnetic field, it will not be possible to heat up the plasma core by electron cyclotron resonance heating since the electromagnetic waves will be reflected at the critical density. For a temperature of 1 keV, the electron β-value limit is as low as 0.4% for the ordinary wave and 0.8% for the extraordinary wave. There are two ways to get around this problem. One is to use the second harmonic of the cyclotron frequency and the other is to perform a mode conversion to Bernstein waves inside the plasma. The electron Bernstein waves can pass the layer of critical density and will be strongly absorbed at the position where the frequency is equal to the electron cyclotron frequency. DANTE seems to be quite suitable for mode conversion experiments, since the plasma frequency is higher than the electron cyclotron frequency in the centre by up to a factor of two. A plasma layer of critical density therefore encircles the centre and a mode conversion from an ordinary wave to an extraordinary electromagnetic wave should take place at this position. The other possible mode conversion will take place at the upper hybrid resonance layer where an extraordinary mode can be converted to an electrostatic electron Bernstein wave, which in turn will propagate to the plasma centre where it will deposit its energy.

Authors: (7,8,18,14)

2.1.12. Ray tracing of electron cyclotron waves

To obtain detailed information about how electron cyclotron waves propagate in a tokamak plasma, a computer program solving the ray tracing differential equations has been developed. This program calculates the rays in three dimensions in a toroidal geometry and takes into account the mode conversion which takes place at the layer of critical density ($\omega=\omega_{pe}$) where the ordinary wave is converted to an extraordinary wave and the mode conversion at the upper hybrid layer where the extraordinary wave is converted to an electron Bernstein wave. Wave absorption in the plasma is computed according to results found from analytical calculations.

Authors: (18,7,8)

2.1.13. A review on double layers in plasma

A review paper for the APS meeting, 1982.
A double layer is a potential structure which separates two plasmas of different temperatures and densities. The paper reviewed some of the main results on electrostatic double layers obtained from the theory, computer simulation, laboratory measurements, and space experiments. Double layers can be regarded as BGK-equilibria and can be classified into different kinds according to the variation of the potential through the double layer and the type of particle distributions on each side of the double layers. Stationary double layers have recently been observed in several experiments and both one-dimensional and three-dimensional features have been investigated. The experimental results seem to support the general picture of double layers, but many problems are not well understood. In particular, our understanding of double layer stability and the process of double layer formation is far from complete. However, progress has recently been made within this field, both theoretically and experimentally. Several recent experiments have given strong evidence for the existence of double layers in the ionosphere and in the magnetosphere. A thorough knowledge of the double layer phenomena seems to be of crucial importance for our understanding of positive columns, plasma diodes and confinement in tandem mirrors.

Author: (8)

2.1.14. Drift wave turbulence in low β plasma

A review paper for the 1982 International Conference on Plasma Physics:
Experimental investigations of strong tubulence associated with the radial density gradient of a rotating magnetized plasma column were reported. The experiment was designed to make Taylor's hypothesis effective, in order to allow a simple interpretation of measured frequency spectra in terms of wave-number spectra. The spectral index of the turbulent potential fluctuations was determined and the variation of the spectral intensity investigated for varying magnetic fields. The results compared favourably with theoretical predictions. The importance of distinquishing subranges in the turbulent spectrum was demonstrated. Some aspects of the relative diffusion of a test cloud of charged particles released in the turbulent field were discussed.

Author: (10)

2.1.15. Effects of trapped particles on strongly nonlinear electron plasma waves

A review paper for the 1982 International Conference on Plasma Physics:
The propagation properties of strongly nonlinear electron plasma waves, i.e. waves for which the amplitude does not satisfy the condition $e\phi/T_e << (V_e/V_p)^2$, were investigated using a numerical simulation. The main features that were found are: a strongly enhanced initial damping as compared with the linear case, amplitude oscillations which persist for many bounce periods, and the formation of BGK-equilibria or the so-called electron holes. Recent experimental observations of single electron holes were reviewed and in particular their mutual interactions were discussed with the help of results from a numerical simulation, modelling the experiment.

Author (11)

2.1.16. Evolution of externally excited convective cells in a plasma

Investigations of convective cells were performed in the Q-machine plasma. The cells were excited externally by controlling the end losses of electrons, and their space-time evolution was investigated by two-dimensional potential measurements. A positive cell was excited externally in the "scrape-off" layer of a plasma column. Its interaction with the main plasma produced a new cell with negative polarity. The two cells propagated close to each other and interacted only through a mutual perturbation of orbits.

Authors (10,11,19,33)

2.1.17. Nonlinear ion acoustic waves in a Double-Plasma device

An experimental investigation of the diffraction of nonlinear ion acoustic waves was initiated. The waves are launched by standard operation of a Double-Plasma device. The waves propagate towards a metal plate with a circular aperture. The diffraction of the nonlinear waves at this opening was investigated, with particular attention to the change in their harmonic content. In the same experimental set-up, we have observed the generation of lower harmonics of an applied monochromatic wave.

Authors: (31,10,11,32,33,19)

2.1.18. Stochastic generation of continuous wave spectra

Wave packets of electromagnetic or Langmuir waves trapped in a well between oscillating reflectors were considered. An equation for the temporal evolution of the probability distribution for the carrier wavenumber was derived, and solved analytically in terms of moments in the limits of long and short wavelengths. The relevance of the results for self-generated stochasticity for harmonically oscillating reflectors was pointed out, and the physical implications of the results were discussed.

Authors: (36,10,44)

2.1.19. On the transient effects of nonlinear wave propagation in magnetized plasmas

Approximate analytical solutions using self-similar variables were obtained for the set of coupled nonlinear partial differential equations which govern the evolution of a steep wavefront propagating perpendicular to an externally applied homogeneous magnetic field. In the early stages of the evolution, we found that several of the features noted in a numerical solution of these equations* were predicted by these approximate solutions.

*Pécseli, H.L. and Thomsen, K. (1982) Physics Scripta T2/2, 541-545.

Authors: (31,10,11,19)

2.1.20. Upper hybrid wave collapse in weakly magnetized plasmas

The collapse of electrostatic upper hybrid waves in weakly magnetized plasmas was considered. Attention was paid to dispersive low frequency waves in the equations governing the ion dynamics. In particular, we found that lower hybrid waves will be of great importance for the nonlinear evolution of the upper hybrid wave field for even very low magnetic fields (i.e. electron cyclotron frequency $\omega_{ce} << \omega_{pe}$ electron plasma frequency). Considering a magnetic field alligned cylindrical collapse we demonstrated, by numerical solutions of the evolution equations, that a magnetic field can delay or even prevent a collapse, in comparison with the unmagnetized case. These results are qualitatively explained theoretically, using arguments based on a "virial theorem".

Authors: (10,11,19,34,38)

2.1.21. Langmuir wave collapse

Different descriptions for the collapse of Langmuir waves in a plasma were considered. Among these were different self-similar models and the description based on the "virial theory". In particular, we have re-examined the results of a recent work where the collapse of Langmuir waves is described in terms of the Zakharov equations (Tskhakaia 1982). On the basis of both a "virial theorem" and a self-similar transformation, Tskhakaia claims to demonstrate that the collapse has a two dimensional character. However, we have found serious objections to Tskhakaia's arguments and conclusions. Thus we found no firm justification for his claims that the collapse is two-dimensional, arguing that his virial theorem is derived from an unphysical weight function and that his self-similar solutions only represent a subclass of all approximate collapsing solutions.

Tskhakaia, D.D. (1982) Phys. Rev. Lett. 48, 484-487.

Authors: (11,32,19)

2.1.22. A statistical theory on the turbulent diffusion of Gaussian puffs*

The relative diffusion of a Gaussian cloud of particles is related to a two-particle covariance function

$$R_{abs}(\xi_{ij},\tau) = \overline{u(x_i(t))u(x_i(t-\tau) - \xi_{ij})}$$

in a homogeneous and stationary field of turbulence. This two-particle covariance function expresses the velocity correlation between one particle (i) which at time t is in the position x_i, and another particle (j), which at the previous time $t-\tau$ is displaced the fixed distance ξ_{ij} relative to $x_i(t-\tau)$. For $\xi_{ij} = 0$, R_{abs} reduces to the Lagrangian covariance function of a single particle. Setting, on the other hand, the time lag τ equal to zero, a pure Eulerian fixed point covariance function results. For diffusion times that are small compared to the integral time scale of the turbulence, simple expressions are derived for the growth of the cloud's standard deviation $\sigma(t)$ by assuming that the wavenumber spectrum corresponding to the Eulerian space covariance $R_{abs}(\xi_{ij},0)$ can be expressed as a power law δk^p, where δ is a constant. For instance, by setting $p = -5/3$, an initially small cloud is found to grow as

$$\sigma^2(t) = (2\Gamma(2/3)\delta)^{3/2}t^3,$$

in agreement with Batchelor's** inertial subrange theory. The results were also applied to the relative diffusion of a test cloud of ionized material released in a turbulent plasma. Using experimentally determined drift wave spectra, a particularly rapid expansion of the cloud behind a small plasma-refuelling pellet was predicted, for the initial phase, where it enters the plasma.

* See also 3.1.5.
**Batchelor, G.K. (1950). Quart. J. Roy. Met. Soc. 76, 133-146.

Authors: (46,45,10)

2.2. Participants in the work in plasma physics

Scientific Staff

1. Andersen, S.A. (2.1.5)
2. Andersen, V. (2.1.3, 2.1.4)
3. Chang, C.T. (2.1.6, 2.1.7, 2.1.8, 2.1.9)
4. Jensen, P.B. (2.1.3, 2.1.4)
5. Jensen, V.O.
6. Kofoed-Hansen, O. (part-time)
7. Lynov, J.P. (2.1.11, 2.1.12)
8. Michelsen, P. (2.1.11, 2.1.12, 2.1.13)
9. Nielsen, P. (2.1.10)
10. Pécseli, H.L. (2.1.14, 2.1.16, 2.1.17, 2.1.18, 2.1.19, 2.1.20, 2.1.22)
11. Rasmussen, J.J. (2.1.15, 2.1.16, 2.1.17, 2.1.19, 2.1.20, 2.1.21)
12. Schou, J. (2.1.1., 2.1.2, 2.1.5)
13. Sørensen, H. (2.1.1, 2.1.2, 2.1.5)
14. Weisberg, K.V. (2.1.5, 2.1.11) (part-time)

Ph.D. Students

15. Bejder, H. (2.1.3, 2.1.4)
16. Børgesen, P. (until 30th June)(2.1.1, 2.1.2)
17. Gadeberg, M. (2.1.10)
18. Hansen, F.R. (from 15th September)(2.1.11, 2.1.12)
19. Thomsen, K. (2.1.7, 2.1.8, 2.1.9, 2.1.16, 2.1.17, 2.1.19, 2.1.20, 2.1.21)

Technical Staff

20. Andersen, P.
21. Borman, K. (2.1.5)
22. Hansen, B.H.
23. Jessen, M. (from 1st September)
24. Nielsen, M.O.
25. Nordskov, A. (2.1.5)
26. Olsen, J. (2.1.5)
27. Petersen, J. (until 20th May)
28. Reher, B.
29. Sass, B. (2.1.5)

Guest Scientists

30. Čadež, V. (Institute of Physics, Beograd, Yugoslavia)
31. Lonngren, K.E. (2.1.17, 2.1.19) (The University of Iowa, U.S.A.)
32. Rypdal, K. (2.1.17, 2.1.21) (Tromsø University, Norway)
33. Sugai, H. (2.1.16, 2.1.17) (University of Nagoya, Japan)

Short-time visitors and collaborators outside Risø

34. Christiansen, P.L.(2.1.20) (Technical University of Denmark)
35. Clausen, C.(2.1.2) (University of Odense)
36. Dysthe, K.B. (2.1.18) (University of Tromsø, Norway)
37. Jovanović, D. (Institute of Physics, Beograd, Yugoslavia)

38. P. Lomdahl (2.1.20)	(Technical University of Denmark)
39. Maroli, C.	(University of Milano, Italy)
40. Petrillo, V.	(University of Milano, Italy)
41. Sato, N.	(Tohoku University, Sendai, Japan)
42. Schrittwieser, R.	(Innsbruck University, Austria)
43. Tchen, C.M.	(The City University of New York)
44. Trulsen, J. (2.1.18)	(University of Tromsø, Norway)

Collaborators inside Risø

45. Larsen, S.E. (2.1.22)	(Physics Department, Metereology Section)
46. Mikkelsen, T. (2.1.22)	(Physics Department Meteorology Section)

Students working for their Master's theses

47. Jørgensen, J.	(Technical University of Denmark)
48. Hansen, F.R. (2.1.11, 2.1.12)	(Technical University of Denmark)

2.3 Publications and educational activities

2.3.1. Publications

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THOMSEN, K. Nonlinear transient wave propagation in magnetized plasma. 17th Nordic Symposium on Plasma and Gas Discharge Physics, Geilo, Norway, February 2-5.

2.3.3. Lectures

ANDERSEN, V. Fusionsenergi (Fusion energy). Energi, Sikkerhed Miljø, Bellacentret, Copenhagen, Denmark (December).

CHANG, C.T. On the use of Langmuir probe in a laser-produced plasma. Department of Electron and Plasma Physics, Royal Institute of Technology, Stockholm, Sweden (September).

CHANG, C.T. On the correlation between the H_α-line emission rate and the ablation rate of a refuelling pellet. Fontenay-aux-Roses, Paris, France (November).

GADEBERG, M. Thomsonspredning på høj- og lavtemperatur plasma (Thomson scattering in high and low temperature plasmas). Technical University of Denmark, Lyngby, Denmark (August).

JENSEN, V.O. JET og den europæiske fusionsforskning (JET and the European fusion research). Kerneteknisk Selskab, Ingeniørforeningen, Copenhagen, Denmark (March).

JENSEN, V.O. Fusionsenergi (Fusion energy). Lecture given to physics and chemistry teachers, Frederiksborg Amt, Denmark (October).

JENSEN, V.O. JET og europæisk fusionsforskning (JET and European fusion research). Participation in a TV-programme (June).

JENSEN, V.O. Plasma Physics I and II. (Two lecture series on plasma physics and fusions research). Technical University of Denmark, Lyngby, Denmark.

NIELSEN, P. The single point Thomson scattering system on JET. JET, Culham, England (October).

PÉCSELI, H.L. Central Research Institute for Physics of the HUNGARIAN Academy of Sciences, Budapest, Hungary (May).
1) Research in plasma physics at Risø National Laboratory.
2) Field-aligned striations in ionospheric heating experiments.

PÉCSELI, H.L. Institute of Physics, Beograd, Yugoslavia (August).
1) Research in plasma physics at Risø National Laboratory.
2) Weakly nonlinear plasma waves.

PÉCSELI, H.L. Ionospheric heating experiments. Faculty of Electrical Engineering, Beograd, Yugoslavia (September).

PÉCSELI, H.L. Fontenay-aux-Roses, Paris, France (September).
1) Electron phase-space vortexes. Theory and Experiment.
2) Ion phase-space vortexes and their relation to the ion two-stream instability.

PÉCSELI, H.L. Stochastic wave reflection and the Fermi-acceleration problem. Danish space Research Institute, Lyngby, Denmark (October).

RASMUSSEN, J. JUUL. Ideas for future activities in experimental plasma physics. Colloquium at Tromsø University, Tromsø, Norway (June).

SCHOU, J. Plasma-pellet work at Risø National Laboratory. Oak Ridge National Laboratory, Tennessee, USA. (May).

SCHOU, J. Transport theory for secondary electron emission. National Bureau of Standards, Radiation Theory Section, Washington D.C., USA. (May).

THOMSEN, K. Numerical solution of nonlinear partial differential equations by a finite difference method. University of Tromsø, Tromsø, Norway (August).

3. METEOROLOGY

3.1. Introduction to work in meteorology

The basic subject for research and applied work is known under the general term micrometeorology. The term was introduced by Sir O.G. Sutton 30 years ago, a few years before work on the subject actually started at this institution. The various components under this heading include a range of subjects from surface energy balance studies, of importance for example in such diverse areas as road administration (icing conditions) and bio-meteorology (evaporation and shelter effects) over studies of the general structure of atmospheric coherence, and boundary layer response to change in surface elevation, both of interest in civil and wind power engineering) to specific studies of turbulent dispersion and deposition of airborne material (evaluation of air pollution potentials). Due to the latter being partly a climatological problem, climatology is also considered a subject which must be covered. Further, data aquisition and measurement techniques are necessary diciplines. In the later years research and development in the utilization of wind energy has become a particular subject (evaluation of wind resources, turbulent effects on generator performance). The activities of The Test Plant for Small Wind Mills, although part of the Meteorology Section, are reported in a separate chapter (4) to give further opportunity to outline the working programme.

3.1.1. Comparison between dispersion meteorological statistics from different sites in Denmark*

Dispersion meteorological statistics (wind-speed and -direction and Pasquill-stability class) have been established for a number of sites in Denmark. The statistics is based on tower measurements in the lowest 30 m of the boundary layer.

Yearly distribution of wind directions and Pasquill-classes were found to be equal for all in-land stations in the comparison, while systematic differences were found between the Pasquill-class distributuions over land and water. The differences in the wind speed distributions at the different sites can largely be explained by roughness differences.

*Supported by ELSAM and ELKRAFT.

Authors: (4,6,9)

3.1.2. A tracer investigation of the dispersion of airborne releases from uranium mining at Kvanefjeld in Greenland*

Experimental work was carried out in the summer of 1981; the observed characteristics of the dispersion and flow field in the valley are described in the progress report of 1981. In 1982 a final report has been written that describes the experiments. Also work was been carried out in order to simulate the flow-field in the valley, however, a theory that satisfactorily describes the observed flow has not been formulated yet.

*Supported by the Uranium Project, Risø National Laboratory

Authors: (9,6,41)

3.1.3. A tracer investigation of the atmospheric dispersion in the Øresund region*

The atmospheric dispersion in the Øresund region was investigated by carrying out tracer experiments. The tracer sulphurhexafluoride was released at a height of 95 m from the meteorological tower at the nuclear power station Barsebäck in Sweden, which is situated at the eastern coastline of Øresund. Tracer sampling units were placed in Copenhagen in two series, one very close or even directly to the water front, and the other about 2-4 km inland. Thus, the tracer was relased over land close to the water front, then it was advected over a water surface of about 20 km, reaches the opposite land surface and is then sampled very close to the water front before the tracer actually will be influenced by the land surface, and was further sampled about 2 km inland. Measurements of temperature, windspeed and direction were during the experiments performed at several places in meteorological towers and by use of radiosondes and pilot balloons. Data from the one successful experiment are reported in Gryning et al*. The experimental results were simulated by the Enger** model. The mean wind and the turbulence quantities are simulated with a second order closure atmospheric boundary layer model. The lateral dispersion is handled with a Gaussian approach. The standard deviations are obtained from model generated standard deviations of the lateral wind component with Taylor's expression and Eulerian spectra. The model simulations are in very good agreement with the experimental results.

* Gryning, S-E., Lyck, E. and Widemo, U. (983). A tracer investigation of the atomospheric dispersion in the Öresund region. Data and Technical report. Studsvik Energiteknik AB, Sweden. 83/NW-83/452.

**Enger, L. (1983). Numerical boundary layer modelling with application to diffusion. Part I: A two dimensional higher order closure model. Part II. A higher order closure dispersion model. Department of Meteorology, University of Uppsala, Report 70-71. Part I, 54 pp, ISBN 91-506-0385-x. Part II, 45 pp, ISBN 91-506-0386-8.

*Supported by Studsvik AB, Sweden

Authors: (9,36,41,52)

3.1.4. Double tracer experiments to verify atmospheric dispersion models of fission products

The experiments were carried out in 1981 and described in last years progress report. The data evaluation has been continued, including the determination of the relevant meteorological parameters. The estimation of the plume height was a special problem due to the low excess temperature of the plume and due to downdraft along the chimney. Simulations of the experiments by use of Risø's Plucon and Studsvik's Unidose models are presently being carried out.

Authors: (9,36,41,43)

3.1.5. A statistical theory on the turbulent diffusion of Gaussian puffs*

The relative diffusion of a one-dimensional Gaussian cloud of particles have been related to a two-particle covariance function $R_{abs}(\xi_{ij},\tau) = \langle u(x_i(t))u(x_i(t-\tau)-\xi_{ij})\rangle$ in a homogenous and stationary field of turbulence. This two-particle covariance function expresses the velocity correlation between one particle (i) which at time t is in the position x_i, and another (j), which at the previous time $t-\tau$ is displaced the fixed distance ξ_{ij} relative to $x_i(t-\tau)$. For $\xi_{ij} = 0$, R_{abs} reduces to the Lagrangian covariance function of a single particle. On the other hand, setting the time lag τ equal to zero, R_{abs} becomes a pure Eulerian (fixed point) covariance function. For diffusion times that are small compared to the Lagrangian integral time scale of the turbulence, simple expressions have been derived for the growth of the standard deviation $\sigma(t)$ of the cloud by assuming that the wave number spectrum corresponding to the Eulerian space covariance $R_{abs}(\xi_{ij},0)$ can be expressed as a power law function δkP, where δ is a constant with dimension of $[\text{length}]^{(1+p)}$. For instance, by setting $p = -5/3$, an initially small cloud is found to growth as $\sigma^2(t) = \langle u^2\rangle^{3/2}(2\Gamma(2/3)\delta)^{3/2} t^3$ in agreement with Batchelor's** inertial subrange theory. Correspondingly, for the enstrophy cascade subrange in two-dimensioal turbulence, for which case $p = -3$, the theory yields $\sigma^2(t) = \sigma_o^2 \exp(\langle u^2\rangle\delta t^2)$, where σ_o denotes the initial size of the cloud.

* See also 2.1.22
**Batchelor, G.K. (1950). Quart. J. Roy. Met. Soc., 76, 133-146.

Authors: (6,10,11)

3.1.6. A parametric description of a skewed puff in the diabatic surface layer

Work has been done on a model for the dispersion of a ground-level released puff of passive contaminants in a diabatic stratified surface layer. The model is intended for use in predictions of pollutant concentrations in connection with an operational puff diffusion model, where a series of puffs are emitted successively from the source. The horizontal concentration profiles are assumed to be of Gaussian shape. The shape of the vertical concentration profile is taken to be a function of the atmospheric stability, described through a shape parameter, q. An approximate analytical expression for q have been suggested, that compares favourably with numerically derived values of the q-function. The shearing of the puffs have been calculated by tagging the position of two tracer particles, displaced by the distance Fz about the mean height of the puff z. The value of the constant F have been determined in a way such that the horizontal spread of the cloud equals the theoretical predictions of the spread that results as a consequence of the interaction of the wind shear and the vertical dispersion. Numerical examples indicate that the mean height of the puffs as well as the shape parameter are strongly influenced by changes in atmospheric stability, however, the total horizontal spread of the puff was found to vary only little over a broad range of the atmospheric stability.

Authors: (9,10)

3.1.7. Dry deposition, surface production and dynamics of aerosols in the marine boundary layer

A model of aerosol dry deposition velocity, V_d, due to Slinn and Slinn* is generalized to the case of nonzero surface concentration (absorbing surface with a surface source). The general expression for V_d is incorporated into a dynamic mixed layer model of the type developed by Davidson et al.**. This three layer model (diffusion sublayer, turbulent surface layer, and mixed layer) is applied to an open ocean marine regime where boundary layer advection is ignored. The aerosol concentration in the boundary layer is considered to consist of sea salt particles produced as droplets at the surface and "continental" background aerosols brought into the boundary layer at the top by entrainment and gravitational settling. Assuming an average equilibrium state, the droplet production rate, S_o, can be related to the surface layer turbulent eddy flux.

* Slinn, S.A. and Slinn, W.G.N. (1980). Atmos. Environ. 14, 1013-1016.

**Davidson, K.L. Fairali, C.W. and Schacher, G.E. (1983) An analysis of the surface production of sea salt particles Tellus (submitted).

Authors: (6,20)

3.1.8. Summary and interpretation of Danish climate statistics*

A summary of available Danish climate statistics have been prepared (Risø-Report-399). The main physical processes of relevance have been described along with graphical presentation of the various climate parameters. Finally, a complete set of the data used has been tabulated. A study of 100-year records of weather data from selected Danish stations is in progress. The purpose is to find evidence of climate variation over the last century.

*Supported by CEC under contract No. CLI-049-DK(G)

Authors: (4,6,22)

3.1.9. Study of local wind flow at potential WECS hill sites

The objective of this task is to carry out a major cooperative field experiment to measure in detail the spatial characteristics of mean wind and turbulence over a typical WECS (Wind Energy Conversion System) hill site. Such information is not presently available and is badly needed in order to improve existing knowledge of the modification of airflow caused by local terrain features at potential WECS sites. The data would yield information on both the "speed-up" of mean wind over the hill (and hence the additional energy available above that at a flat terrain site) and on the modifications to turbulence levels and structure produced by the hill. These data would then be compared with mathematical and physical (wind tunnel) models in order to assess the faithfulness with which such models can predict the actual flow. After a careful survey, the hill "Askervein" on the Hebredies was chosen. The upstream terrain is rather homogeneous; the height and length scale of the hill is as large as can be managed with conventional micrometeorological techniques; the hill shape is fairly simple; and there is a large scale separation between the hill and smaller features or bumps on it. Two 50 m towers for turbulence and mean profile measurements were deployed, one at hill top and one for upstream reference. For measuring the horizontal wind distribution, 35 6 m poles with cupanemometers were placed along a line running over the hill in the predominant wind direction. Data analysis is in progress. A second experimental compaign is planned for 83. Teams from Canada, FRG and U.K. is participating.

Authors: (4,25,28,29,35,42,44,46,47,48)

3.1.10. Wind Atlas for the European Community

From a windflow point of view the terrain of the CEC countries is classified into five terrain forms spanning from non-mountainous uncomplicated terrain to high mountain massifs. For the two least complicated terrain forms a method is being developed which will make it feasible to obtain an as accurate as possible estimate of the wind velocity at a given height above a specified terrain. The physical base for the method is the similarity theory for the planetary boundary layer. The method requires several long climatological wind speed records from each country from very homogeneous areas. These series are used to establish the climatology of the synoptic forcing for the region under consideration. The method then utilizes the forcing climatology to calculate the wind speed statistics over various terrains in the region. The Weibull distribution is fitted to the calculated wind speed distributions and the results will then be presented as charts giving the Weibull parameters for a region as function of terrain, direction sector and height up to 200 meters.

For the complicated mountainous terrain recourse is taken to numerical models. An assessment is made of the models and selected models are tested at two speicfied sites in Italy and Greece. Finally, the selected models will be applied to the various complicated areas in the CEC to produce results of general applicability in the regions under consideration.

Authors: (8,11,4,24,26,30,38,39,45,49,53)

3.1.11. Development of the utilization of wind energy in Cap Verde

A development project concerning the utilization of wind energy on the Cap Verde Islands was effectively started May 1982. The project is financed by Danida, and executed by the United Nations Development Programme. Risø has been appointed as a consultant to the project, which include the installation of a number of wind turbines for electricity production. Cap Verde is placed in the trade wind belt where the wind direction most of the year is North-East. The wind speed distribution is characterized by its narrowness and the energy flux (kWh m^{-2} $year^{-1}$) is large, providing good possibilities for economic utilization of wind energy. Besides the installation of wind turbines, the project includes site evaluation, training of Cap Verde engineers and technicians and system design of a combined diesel and wind turbine power plant. The project will be terminated by the end of 1985.

Authors: (1,2,7,23)

3.1.12. Dynamic loading of wind turbine structures; fatique life evaluation*

A model - or rather a set of models - has been developed, which describes the response of a wind turbine rotor exposed to the random and deterministic loads due to atmospheric turbulence, gravity forces, etc. The model is aimed at the prediction of the lifetime for vital structural components, and includes calculations of fatique life as well as extreme responses.
The structural model including the external loads is considered to be linear so that a frequency domain description of the response is possible. This description provides the basis for a true probabilistic evaluation of the consequences of the combined stochastic and deterministic loading.
On the basis of the analytical model, a computer programme has been developed which is highly efficient with respect to computation times when compared to other programmes made for similar purposes. Also the program gives for the first time a proper description of the combined effects of all the pertinent load cases. The development of the model is continuing in 1983.

*Work supported by The Electric Utilities of Denmark and The Ministry of Energy.

Authors: (1,2,7,21)

3.1.13. Design of control systems for pitch regulated wind turbines

Pitch angle regulation is often used as a mean of limiting the maximum power output of a wind turbine. The atmospheric conditions with respect to wind profiles and turbulence as function of the thermal stability of the atmosphere exhibit very large variations, and must be taken into account in the design process of the pitch regulation system. The wind turbine only senses variations in wind speed that have spatial dimensions larger than the rotor dimensions, the rotor acts as a low pass filter, and this places an upper bound on the necessary bandwidth of the control system. The spectrum of wind fluctuations can most often be characterized by the fact that most of the energy lies within say two decades on the frequency axis. This means that if the control system should have any significant effect the bandwidth must be sufficiently large such that there is a reasonable reduction of the influence of the most energetic wind fluctuations, and so this constitutes a lower bound on the bandwidth. A good guideline for the necessary bandwidth is: $0.05u/z < n < 0.3u/z$ where n is the needed bandwidth and z is the rotor dimension and u the mean wind speed at rotor height. The pitch control system of one of the Nibe turbines has been analyzed, and the results compared with measurements of variance spectra of wind fluctuations and power fluctuations.

Author: (3)

3.1.14 PPI-theory for particle dispersion

The probability that a particle released at a source point with a certain initial velocity hits a target point after a specified travelling time has been thought of as the integral over all possible paths which conform to these boundary conditions. With the assumption that a marked particle in a homogenous turbulent fluid moves following a first order autoregressive process, a measure of probability for passage along a certain path has been found, and it was possible to show that the integration over all paths was equal to the integration along one particular path obtained as the solution to the Euler differential equation except for a normalization factor. The method has been generalized to give solutions for the dispersion for a plume tranversing a step change in turbulent velocity variance and Langrangian time scale assuming each particle to have a contineous velocity across the interface of the two homogeneous areas.

Authors: (6,10,11)

3.2. Participants in the work in meterology

Scientific staff

1. Frandsen, S. (3.1.11,3.1.12,3.1.13)
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4. Jensen, N.O. (3.1.1,3.1.8,3.1.9,3.1.10)
5. Kristensen, L. (3.1.12)
6. Larsen, S.E. (3.1.1,3.1.2,3.1.5,3.1.7,3.1.8,3.1.14)
7. Madsen, P.H. (3.1.11,3.1.12)
8. Petersen, E.L. (3.1.10)

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9. Gryning, S.-E. (3.1.1,3.1.2,3.1.3,3.1.4,3.1.6)
10. Mikkelsen, T. (3.1.5,3.1.6,3.1.14)
11. Troen, I. (3.1.5,3.1.10,3.1.14)
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39. Lavanini, A. (3.1.10)	(Instituto di Fisica et del 'Atmosfera CNR, Italy)
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3.3. Publications and educational activities

3.3.1. Publications

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3.3.3. Conference contributions

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3.3.4. Lectures

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GRYNING, S.E. Det atmosfæriske grænselag og de parametre som anvendes til at beskrive det i ustabile, neutrale og stabile situationer. The Technical University of Denmark. (April).

GRYNING, S.E. Elevated Source SF_6 Tracer Dispersion Experiments in the Copenhagen Area. The Technical University of Denmark. (April).

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KRISTENSEN, L. Spatial Structure of Atmospheric Turbulence.
1) University of Washington Seattle, (October).
2) Naval Postgraduate School, Monterey, (October).
3) National Center for Atmospheric Research, Boulder, Colorado. (October).
4) Pensylvania State University State College, (October).
5) State University of New York, Buffalo (October).

KRISTENSEN, L. On Kinematic Description of Atmospheric Turbulence. Two Lectures at State University of New York, Buffalo (October).

KRISTENSEN, L. Squashed Atmospheric Turbulence.
1) University of Washington, Seattle, (October).
2) National Center for Atmospheric Research, Boulder, Colorado. (October).

LARSEN, S.E. Modellering af hastighedsspektra i atmosfærens grænselag. University of Uppsala, Sweden. (June).

LARSEN, S.E. Mixed og dynamisk respons af hot-wires og cold-wires. University of Uppsala, Sweden. (June).

LARSEN, S.E. Experiments and Techniques in the atmospheric Boundary Layer. Nordisk Kollogium for Fysisk Oceanografi. University of Copenhagen. (January).

LARSEN, S.E. Meteorologisk eksperiment i Jylland. Danish Meteorological Society, Copenhagen. (December).

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1) Department of Atmospheric Sciences, Oregon State University, Oregon, (May).
2) Department of Meteorology, Naval Postgraduate School, Monterey, California, (June).
3) Department of Applied Mechanics and Engineering Sciences, University of California, San Diego, California, (June).
4) National Center for Atmospheric Research, Boulder, Colorado, (July).

4. TEST STATION FOR SMALL WINDMILLS

4.1. Introduction to work at the test station

The test station is run as a part of the meteorology section, mainly financed by the ministry of energy (energy research programme and subsidy for renewable energy programmes). It is responsible for the testing and licensing of windmills for the Danish market. At the same time the test station offers consulting assistance for the Danish windmill manufacturers, and it undertakes R & D on the broad field of windmill construction, operation and application.
In 1982 a considerable effort went into the development and testing of a standard test program for windmills. Also the implementation of this program for the first five 5 machines on a routine basis was undertaken. New and renewed licences were given. Work on better licensing criteria was started. Numerous visits to and discussions with manufacturers were part of the programme. R & D is going on in the fields of aerodynamic design of windmill rotors with a view on stall regulation and better power production, coupling onto the electrical grid, dynamic load and lifetime, measurement procedures, turbulence effects. A test machine is being built, that will allow precise measurements of as many forces as possible. Several test benches for specialized blade examinations are under construction.

4.1.1. Development of standard measurements

The increasing sale of windmills in Denmark in 1980/81 brought with it a demand for authorized measurements on windmills. The measurements for a given windmill should be accomplished in a relatively short time, but the contents of the measurements should be comprehensive enough for an adequate description of the windmill. Practical experience at the Test Station has also shown that it is very common for the construction to be changed towards an optimized design after the measurements have been carried out.
These considerations led to the philosophy that the first measurements on a windmill should be carried out with limited, but highly reliable instrumentation, able to reveal the fundamental characteristics of the machine and thereby demonstrate the possible need for changes. We designate the programme "standard mesurements". The standard measurements use three parameters on the windmill and four meteorological parameters. These few sensors allow the measurement of energy production, power regulation, transmission efficiences, starting capability, loads at cut-in, loads at stopping and efficiency of air brakes. The measurements are accomplished within a period of four month, and afterwards a test report is published.

Author: (8)

4.1.2. Standard measurements performed

As a part of the licensing function of the test station (on contract with Energistyrelsen) windmills are tested on a routine basis using the standard measurements programme, that we have developed. This particular testing activity was started late 1981. The first basic standard test was performed on a machine (Black Smith-machine, 22 kW.) which we had followed through three years of continued development and testing. In 1982 five machines were tested. Four of these went through the full standard programme, whereas one went through a reduced programme. Furthermore a datalogging system was tested against the normal test station system.
A throughgoing problem for most of the machines was unsatisfactory power regulation (all stall-regulated). In consequence of this an ongoing program studies the correct design criteria for stall regulation and it is hoped that a recommendation can be worked out during 1983-1984, even though the theoretical basis is not yet available. Other common problems were the correct design of effective air brakes and of mechanical brakes, that are smooth enough in the braking action. When such problems are revealed the manufacturer often change the machine which is subsequently tested again. Therefore most tests take longer than originally expected.
Test reports for all the machines studied are under production.

Author: (10)

4.1.3. Licensing of windmills

Since August 1979 the test station has been responsible for the licensing of windmills marketed in Denmark. The licensing primarily serves to qualify the machines for obtaining a state subsidy.
In 1982 five new types and one prototype were licensed. Furthermore 25 types had their license renewed because of design changes or because the machines can be delivered in several different configurations (e.g. different tower heights).
The development of windmill technology is extremely rapid. Along with this development the licensing criteria must be developed too. From a start with a very simple set of rules putting rather little strain on the manufacturers, the criteria develops into much more detailed requirements, that are also more stringently enforced. It has been decided to formalize the development in the form of a more detailed written set of rules, that will be published within about one year (83/84). These rules will represent only a momentaneous freeze and will form a new basis point for the future development.

Author: (3)

4.1.4. Experimental wind turbine

On industrial windmills it is quite often difficult to get access to various forces, moments or other parameters, that are needed. The machines are usually constructed for producing efficently rather than for allowing access to the parameters, that the researcher needs.
Spurred by this problem, the test plant has embargued on the construction of a machine meant to give access to any parameter, that is of any foreseeable interest. The machine is furthermore meant to be flexible enough to allow the easy mounting of various components like gearboxes, blades, controls etc., that needs testing, i.e. to be a component-test facility.
The machine is meant to carry rotors of diameter up to 15 m. It has a tower height of 15.7 m and a slip-ring inductiongenerator. of 30 kW.
The type of research that is anticipated with this machine is for instance: test of new blade designs, air brake studies and complete mappings of loads in the rotor and other structure.

Author: (4)

4.1.5. Test benches

When reviewing windmills and planning research the need for specialized test benches quickly gets obvious.
A test stand for testing the strength of windmill blades to static loads is being built. On this stand the response to a static load of 300 kN/m^2 of swept rotor area can be tested for blades up to ~ 12 m length. The same bench will later be equipped with instruments for mapping blade profiles to accuracies better better than 1 mm.
A test stand for fatigue testing of blades is being planned.
Furthermore a test stand for measuring losses in the power train is being planned. Especially gear box losses are considered a problem to study.

Author: (4)

4.1.6. Blade and rotor loads on stall-controlled windmills

The aim of this work is twofold. First, a comparison of calculated and measured aerodynamic forces is used for an empirical modification of existing, incomplete profile data. Second, dynamic blade loads in skew wind that are especially large (and harmful) were studied. A VESTAS 15 machine was used.
As existing aerodynamic profile data when used in a Glauert model are not satisfactory, modified data were extracted by an iterative calculation from measured values of the blade root bending moments in two directions (edgewise and flapwise in axial flow) as a function of wind speed. These values are compared to Glauert model calculations giving the moments essentially as integrals of the profile data along the rotor radius. The resulting data were used for predicting dynamic loads in skew wind and compared to measured values as a function of the basic parameters: wind speed, yaw angle and blade position. Fundamental aerodynamic knowledge was ectracted from these comparisons. It is for instance found that a Glauert model modified for skew wind works reasonably well. Finally the statistics of the loads due to instationarity of the wind (turbulence) was measured.

The work will be reported in Risø-M-2392.

Author: (9)

4.1.7. Power curve estimation for stall controlled windmills

The power curve and especially the stalling behaviour of stall controlled windmills can not be predicted well enough. The theoretical models usually used, but especially the existing aerodynamic profile data are rather doubtful (see also 4.1.6) for windmill applications.
In order to gain more insight into this problem, rotor parameter studies are being carried out, both experimentally and theoretically. The variation in rotor efficiency, stall characteristics and blade root moments upon changes in parameters like blade tip angle, tip speed, rotor diameter, and surface roughness is studied. Such results allow us to estimate the parameters that will yield the power curve changes wanted without knowing the pracise profile data. On the other hand such parameter studies also can be used in the empirical deduction of better profile data.
It is our experience that one can get a good part of the way like that and that better profile data measurements especially in the stall region would improve the situation considerably.

Author: (9)

4.2 Participants in the work at the test station for small windmills

Scientific staff

1. Christensen, C.J. (head)
2. Harvøe, P. (administrator)
3. Hjuler Jensen, P. (4.1.3)
4. Krogsgaard, J. (4.1.4,4.1.5)
5. Lading, P.
6. Lundsager, P. (at present at University of Buffalo, USA)
7. Petersen, H. (consultant)
8. Friis Petersen, T. (4.1.1)
9. Rasmussen, F. (4.1.6,4.1.7)
10. Rasmussen, P. (4.1.2)

Technical staff

11. Hagensen, F.
12. Jensen, A.
13. Madsen, J.
14. Nørregård, I.
15. Sørensen, V.

Guest scientist

16. Holley, B. (also in meteorology section).

Furthermore the test station has received several hundred visitors.

4.3. Publications and educational activities

4.3.1. Publications

JENSEN, C.M. (1982). Overførsel af et NEUCC program til Burroughs B6700 Algol. Risø-I-96. 38 pp.

JENSEN, P. HJULER (1982). En vindmølles privatøkonomi. Risø-M-2335, 34 pp.

PEDERSEN, T. FRIIS (1981). Standardmålinger på vindmøller opsat på Prøvestationen for mindre vindmøller. Risø-M-2325: 35 pp.

PEDERSEN, T. FRIIS (1982). Informationsblad om Prøvestationen for mindre vindmøller (November).

PEDERSEN, T. FRIIS (1982). Afprøvning af Smedemestermølle med 22 kW generator og 10 m rotor. Risø-M-2380. 42 pp.

PETERSEN, H. (1982). Small Windmills in Denmark. Updated version of article in Wind Engineering 4 February 1980.

RASMUSSEN, F. and PEDERSEN, T. FRIIS (1982). Measurements and calculations of forces on the blade of a stall-regulated HAWT. Risø-M-2346. 19 pp.

RASMUSSEN, P. (1982). Afprøvning af Ulrik Poulsen vindmølle type 1 fra VPF Maskinfabrik ApS. Risø-M-2338. 38 pp.

RASMUSSEN, P. (1982). Afprøvning af datalogger type SVT-1A fra Tripod Consult ApS. Risø-M-2364. 21 pp.

Newsletter No. 4. March 1982. (in Danish)

Newsletter No. 5. July 1982. (in Danish)

Newsletter No. 6. November 1982. (in Danish)

4.3.2. Lectures

JENSEN, P. HJULER. Vindmøller i Danmark. IS-Sønderjylland (January).

JENSEN, P. HJULER. Om stormskader på vindmøller under stormene november 1981. S.L's-Temadag (March).

JENSEN, P. HJULER. Økonomi for fabrikanter vedr. fabrikationsomkostninger på vindmøller og faktorer af betydning for afsætningsmulighederne for vindmøller. Nordisk Energimesse, Brønderslev (April).

JENSEN, P. HJULER. Gennemgang af forskellige forhold der bør tages hensyn til ved anskaffelse af en vindmølle (November).

JENSEN, P. HJULER. Om vindmøller. DIEU-KURSUS (November).

JENSEN, P. HJULER Foredragsrække om vindmøller for Kommuneingeniører. Energistyrelsen (December).

LUNDSAGER, P. Experience with the Gedser Windmill and small Danish windmills. Asme Wind Energy Symposium. Energy Sources Technology Conference & Exhibition. New Orleans, USA, (March).

LUNDSAGER, P. and JENSEN, P. HJULER, Licensing of windmills in Denmark. Fourth International Symposium on wind Energy Systems, Stockholm, Sweden, (September).

PEDERSEN, H., The 29.3-m diameter Danish wind turbine, 29. 3/3/D, for twospeed operation, Rated at 265/60 kW, 50 Hz. at the Fourth International Symposium on Wind Energy Systems, Stockholm, Sweden.

PEDERSEN, H., Application of wind turbines. Lecture given to the town council, Brest, France, (November).

RASMUSSEN, F. and PETERSEN, T. FRIIS, Measurements and calculations of forces on the Blade of a Stall-Regulated HAWT". Fourth International Symposium on Wind Energy Systems, Stockholm, Sweden (September)

RASMUSSEN, P. Foredrag på distributions elektrikermøde. Danske Elværkers Udredningsforening (DEFU), Middelfart, Denmark (May 26-28).

RASMUSSEN, P. Foredrag on Workshop on New and Renewable Sources of Energy. Arrangeret af (IALA). Farvandsdirektoratet, Oslo, Norway (September 20-24).

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